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Distribution of ^{222}Rn in groundwater and estimation of resulting radiation dose to different age groups: A case study from Bangalore City

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ABSTRACT

Ingesting waters holding high levels of natural occurring radioactive element like Radon would contribute to increase in the effective dose received by people followed by an increased prevalence of cancer. The current study is an attempt to describe the extent of contribution of ^{222}Rn to natural background radiation and the resultant effective dose to public of different age groups. In order to do so, 65 groundwater samples from selected parts of Bangalore city were collected and analyzed for radon activity using RAD7 radon monitor coupled with RAD H_2O accessories. The radon activity was in the range of 3.05–696 Bq/L (mean: 91.39 Bq/L) and 92.31% of the groundwater samples recorded elevated radon concentration above the United States environmental protection agency (USEPA's) Maximum Contaminant Level (MCL) value of 300 pCi/L, corresponding to 11.1 Bq/L. The mean annual effective dose contribution of people falling under different age groups (*viz.*, infants, children, teens: males and females, adults: males and females, pregnant and lactating women) due to ingestion of water-borne ^{222}Rn ranged from 0.082 to 0.444 mSv/y and was found to be higher in all the age groups of males compared to respective female age groups, but well within the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and World Health Organization (WHO) proposed limit of 1 mSv/y.

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age groups; pregnant; lactation; dose conversion factor (DCF); UNSCEAR

Introduction

Drinking water may reasonably be expected to contain at least amount of some contaminants either by natural or anthropogenic means, which may or may not be harmful to living organisms, including humans. It is hard to arrive at conclusion that water may pose a health risk due to presence of certain levels of contaminants, because impact levels are different for different category of contaminants. In spite of the fact that low levels of exposure that occur naturally without any harm, the presence of certain contaminants categorized as radionuclides, especially radon and its progenies in the water, intended for human consumption is a matter of concern. This is because of the fact that unplanned and uncontrolled exposure to

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these radionuclides generally can cause considerable harmful effect in the form of gastric and lung cancers (USEPA 1991) as they deliver large amount of total annual effective dose to human. Although it has been deduced that radon and its short-lived decay products (*viz.*, ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) contribute to about 50% of the global mean effective dose to the public (UNSCEAR 2000), 90% to the total radiation dose received due to radon exposure is contributed by two of its descendent α-emitters, ^{214}Po and ^{218}Po (Gruber *et al.* 2009; Mittal *et al.* 2016).

Radon is readily soluble in water and its solubility decreases rapidly with an increase in temperature. Also, water-borne radon is believed to cause higher health risk than all other contaminants combined appearing in drinking water (Savidou *et al.* 2001) because people are constantly either externally or internally exposed to radioactive materials especially ^{222}Rn through respiration and drinking water (Fakhri *et al.* 2016), contributing to substantial part of radiological hazard. Water-borne radon deliver whole body radiation dose by entering gastro-intestinal tract *via* drinking water. On the other hand, radon being extremely volatile gas, readily escapes from water into indoor air by means of heating, flushing, dishwashing, showering, and other water using activities (Kusyk and Mamont-Ciesla 2002). Consequently, inhalation of the radon escaping from water does not build up in the respective system as most of it is pumped out immediately during breathing due to its long half-life period. However, small fraction of the radon that reaches the interior region of the lungs can damage the DNA in sensitive lung tissue and cause cancer. Moreover, short half-life decay products of radon(^{218}Po and ^{214}Po), being electrically charged, can get deposited over the dust or smoke particles in indoor air, which when inhaled during breathing, decay almost completely in the lungs.

Health-related problems are often linked to higher levels of radon in ground water compared to surface water (Panghal *et al.* 2017) as its levels directly associated with the concentration of its parent element, uranium / radium in the adjacent rocks within an aquifer. As large amount of energy is released in association with α-particle emission during the decay process of radon and its solid progenies. This energy and α-particles have tendency to damage lung tissues, damaging the vulnerable pulmonary epithelium, and may cause long-term effect on DNA (USEPA 1991) by inducing mutation at molecular level. Hence, radon emitted from the water to indoor air constitutes an important and effective source of exposure to internal radiation (Nevinsky *et al.* 2015) and a vital reason of lung and stomach cancer (USEPA 1991). Inhalation of radon is considered to be the second leading cause of lung cancer and ingestion may contribute to a high incidence of cancer risk in stomach and other organs (BEIR VI 1999). During both ingestion as well as inhalation of radon, internally deposit alpha-emitting, short-lived decay products such as ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po (Mittal *et al.* 2016) deliver significant radiological dose to lungs tissues *via* inhalation of air-borne radon and stomach *via* ingestion of radon dissolved in water (Magad 2009). Alpha particles so emitted from the decay of radon and its daughter products can result in cell and molecular changes and lead to lung, stomach, cancer and also other cancers [Binesh *et al.* 2011; Duggal *et al.* 2013]. According to NRC (1999), the estimated cancer risks to population from water-borne radon *via* ingestion and inhalation pathway account for 11% and 89%, respectively.

A wide range of variation in the radon concentration level is subject to origin of water source. Thus, it is very essential to assess the presence of this radionuclide in different water sources, particularly underground sources (Fonollosa, *et al.* 2016) in order to protect the population from consequence of excessive internal radiation exposure from ^{222}Rn (Kumar *et al.* 2017). Many researchers (Binesh *et al.* 2010 & 2011; Fakhri *et al.* 2016; Somlai *et al.* 2007) have recorded significant differences between the effective dose received by infants, children, and adult men and women by using higher conversion factor for infants and children and lower dose conversion factor (DCF) for adults according to their radio-sensitivity. The present research is one such attempt to quantify the concentration of ^{222}Rn in 65 groundwater samples from selected parts of Bangalore city. Effort was also made to explain the variation in annual effective dose received from ingestion of drinking water by the different age groups in humans, namely infants, children, teens, adults along with pregnancy and lactation period in females were accounted using UNSCEAR proposed equations and uniform dose conversion factor of all age groups.

Methodology

Sampling

Bangalore renamed as "Bengaluru" is the sixth largest city in India. Bengaluru lies between the 12°49′ to 13°9′ N latitude and 77°27′to 77°47′ E longitude at an average elevation of 2953 ft. Bengaluru due to its high elevation enjoys a more moderate climate throughout the year. The coolest month is December with an average low temperature of 15.4°C and the hottest month is April with an average high temperature of 32.8°C. Bengaluru is located over ridges delineating four watersheds, *viz.* Hebbal, Koramangala, Challaghatta, and Vrishabhavathi. It has a scope of expansion in all the direction except toward southeast region, where the Tamil Nadu state boundary occurs. The city attracts people on the basis of its global importance as Information Technology and Bio-technology hub of India. Emerging global companies influenced much of the expansion primarily through jobs and development. It spurred a large-scale expansion of housing and infrastructure. As employment opportunities grew, so did the population and migration to the city, particularly good road network connecting peripheral areas. Bengaluru though covers only 0.5% of the geographic area of the state, 4381 persons crams every square kilometers space of the district making it an overwhelming 10.5% of the state's population in 2011 when compared to 2985 people per square kilometers in 2001. Since January 2007, the erstwhile old Bengaluru city jurisdiction was expanded from 226 sq km to 800 sq km and it is now called as Greater Bengaluru.

The bore-hole/well water samples were collected from 65 different deep bore wells during 2014 in separate air-tight, leak-proof glass vials of 250 mL capacity from the source either with the help of a tube attached to the nozzle or by dipping the vial in a bowl of water, which itself is filled with water from the nozzle. The vials were overfilled and capped under the water to prevent any radon leakage. Each well was allowed to operate for at least 10 min to the environment before collecting sample to ensure accurate radon content measurement.

Experimental measurements

The device used and the experimental procedures followed were previously described in the article published by Ravikumar and Somashekar (2014). Closed loop aeration concept was employed to measure radon concentration in groundwater samples *in-situ* using RAD-7 radon analyzer (Durridge Co., USA) connected to RAD H_2O accessory (Figure 1).

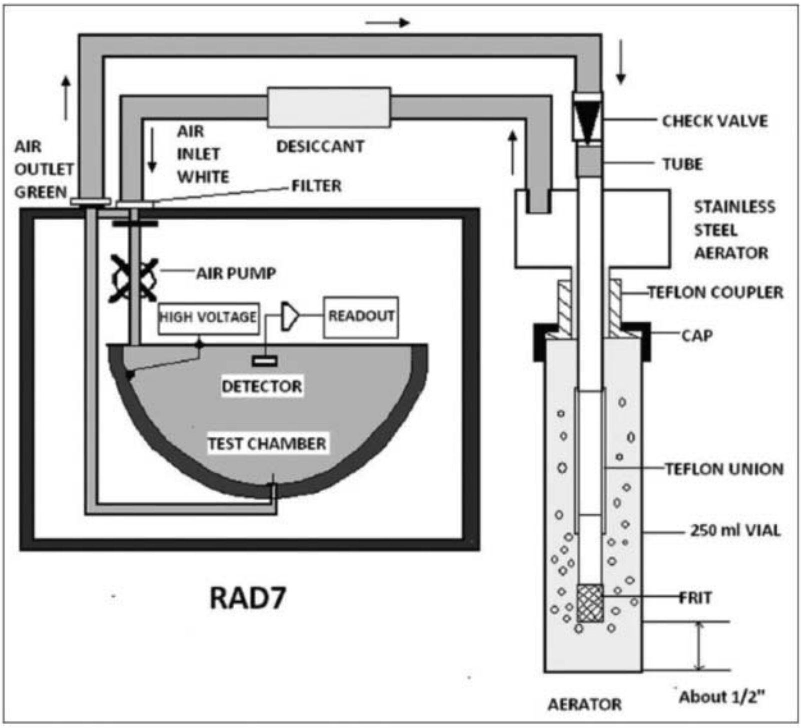

Figure 1. Experimental setup.

Measurement time of 30 min at Wat-250 protocol and Grab mode was followed for all the water samples. A glass vial of capacity of 250 mL containing a water sample is set up in a closed air loop with the RAD7 radon monitor through RAD H_2O accessory system comprising of tube of desiccant supported by the retort and aerator assembly (Ravikumar and Somashekar 2014). The RAD7 with the help of its built-in, internal air pump operates automatically a flow rate of 1 L/min, initially for 5 min to aerate the sample, distributing the radon that was in the water throughout the loop. The RAD7 waits a further 5 min while the ^{218}Po count rate approaches equilibrium and then counts for 4–5 min. The RAD7 pulls samples of air holding expelled radon through a fine inlet filter, which excludes the dust and progeny (*viz*., polonium decayed from radon) into an internal test chamber (which is hemisphere in shape) inside the radon monitor. Inside the RAD7, the polonium was collected onto a silicon solid-state detector in a high electric field in order to estimate radon concentration from court rate of polonium. Overall, the instrument run in a 5 min aeration cycle and of 5 min each four recycles for the measurement of radon activity in water. The average radon concentration in the water samples is then calculated by the instrument from these four cycles directly. Care was taken when sampling the groundwater to ensure that it was never in contact with the open air.

Age-dependent radiation dose

The actual amount of liquid water (from drinks) that an individual needs depends on their age, gender, physical activity, physiological condition or illness and the temperature, and humidity of their physical environment. According to NRC (1977), the daily consumption of water can vary with extent of physical activity and fluctuations in temperature and humidity and that people who live in warmer climates might have higher intakes of water. The present study utilized the prescribed water intakes rates (Table 1) for different age groups (DRIs 2005) as given in the article by Yadav *et al.* (2014) and Duggal *et al.* (2016) to calculate the radiation dose due to intake of radon through ingestion of drinking water pathways for different age groups using the following equation:

$$E_{\mathbf{ing}} = C_{\mathbf{Rn}}\mathbf{x}\ W_{\mathbf{Intake}} \times T \times 1000 \times DCF$$

where

E =	the annually received effective dose due to radon ingestion (in mSv/y)
C_{Rn} =	Concentration of ^{222}Rn (in Bq/L)
W_{Intake} =	the daily consumed water (in L/d)
T =	the time span of water consumption (here 365 d)
1000 =	the conversion coefficient of Sv to mSv.
DCF =	Effective dose coefficient from ingestion of ^{222}Rn (here 3.5×10^{-9} Sv/Bq or 3.5nSv/Bq; NRC 1998)

Results and discussion

Distribution of radon concentration

The mean concentration of ^{222}Rn activity obtained from four counting cycle was used to plot distribution plot for Bangalore city. ^{222}Rn concentration distribution in ground water of Bangalore city is shown in Figure 2 and ranged from 3.05 to 696 Bq/L, with a mean of 91.39 Bq/L. The obtained results were compared with different action levels recommended by USEPA (1991), UNSCEAR (2008), and European commission (2001) on the protection of public against the exposure to radon in drinking water supplies. Accordingly, 92.31% of the samples (*viz.*, 60 samples) showed radon concentration above the MCL value of 300 pCi/L, corresponding to 11.1 Bq/L or 11.1 kBq/m^3 given by USEPA (1991; 1992a, 1999). In contrast, the measured radon activity concentration in 47.69% of the samples (*viz.*, 31 groundwater samples) was above the reference range of 4–40 Bq/L given by UNSCEAR (2008). Similarly, the recorded radon concentrations were compared with the European Commission (EU 2001) recommended action level of 100 Bq/L for pubic water supplies; and it was apparent that radon concentration exceeded the action level in 20% of samples (*viz.*, 13 groundwater samples). The mean and the range values of radon concentration recorded in the present study are on higher side compared to the result reported by Kumar *et al.* (2017) and Panghal *et al.* (2017); Kumar *et al.* (2017) documented comparatively low levels of radon ranging from 2.80 to 74.37 Bq/L (average: 29.37 Bq/L) in water samples from Reasi district, lesser Himalayas of Jammu and Kashmir State, India, while Panghal *et al.* (2017) reported the levels of radon to vary from 16.06 to 57.35 Bq/L (average: 32.98 Bq/L) in the drinking water samples of four districts of Haryana, India. On the other hand, the present results were on the lower side when compared with the results of Prasad *et al.* (2009) as the latter reported radon concentration ranging from 8–3047 (average: 510 Bq/L) in the groundwater collected and analyzed from parts of Garhwal Himalayas, India.

Table 1. Age groups along with their water intake rate and effective dose.

			Water intake rate		Mean effective dose per litre (nSv/L)			Mean effective dose (mSv/y)			
Life stage	Age group	Sex	L/day	L/year	Min	Mean	Max	Min	Mean	Max	Percentage of samples exceeding 0.1 mSv/y
Infants	0–6 months	—	0.7	255.5	3.7	112.0	852.6	0.003	0.082	0.622	20.00
	7–12 months	—	0.8	292.0	4.3	127.9	974.4	0.003	0.093	0.711	20.00
Children	1–3 years	—	1.3	474.5	6.9	207.9	1583.4	0.005	0.152	1.156	29.23
	4–8 years	—	1.7	620.5	9.1	271.9	2070.6	0.007	0.198	1.512	43.10
	9–13 years	Male	2.4	876.0	12.8	383.8	2923.2	0.009	0.280	2.134	55.38
		Female	2.1	766.5	11.2	335.9	2557.8	0.008	0.245	1.867	49.23
Teenagers / teens	14–18 years	Male	3.3	1204.5	17.6	527.8	4019.4	0.013	0.385	2.934	70.77
		Female	2.3	839.5	12.3	367.8	2801.4	0.009	0.269	2.045	50.77
Adults	> 18 years	Male	3.7	1350.5	19.7	591.7	4506.6	0.014	0.432	3.290	73.85
		Female	2.7	985.5	14.4	431.8	3288.6	0.011	0.315	2.401	61.54
	19–50 years	Pregnant women	3.0	1095.0	16.0	479.8	3654.0	0.012	0.350	2.667	66.15
	19–50 years	Lactating women	3.8	1387.0	20.3	607.7	4628.4	0.015	0.444	3.379	73.85
Mean			2.3	845.6	12.4	370.5	2821.7	0.009	0.270	2.060	–

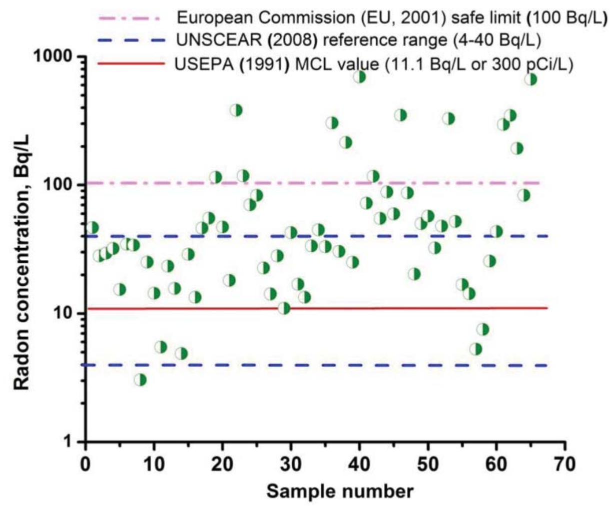

Figure 2. Variation in radon concentration in the study area.

Frequency distribution graph of radon in groundwater samples of Bangalore city is shown in Figure 3 and it well fits to a typical log-normal distributions. About 20% locations of the study area (*viz.*, 13 samples) witnessed very high radon concentration above 100 Bq/L although 80% of the samples were found to hold radon concentration in the range of 0–100 Bq/L. This significant deviation in the concentration of ^{222}Rn across Bangalore city can be the result of difference in depth of water table, production process, remaining time, and water temperature (Ali *et al.* 2010; Ishikawa z*et al.* 2005), emanating/residence time, *etc.*

Dose assessment per liter

The results of the annual effective dose due to intake of ^{222}Rn through drinking water for different age groups can be found in Table 1. Among all age groups, the mean effective dose per

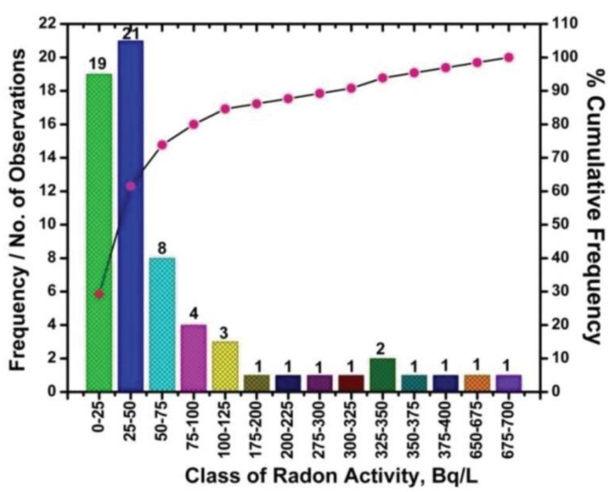

Figure 3. Frequency distribution showing variation in radon activity.

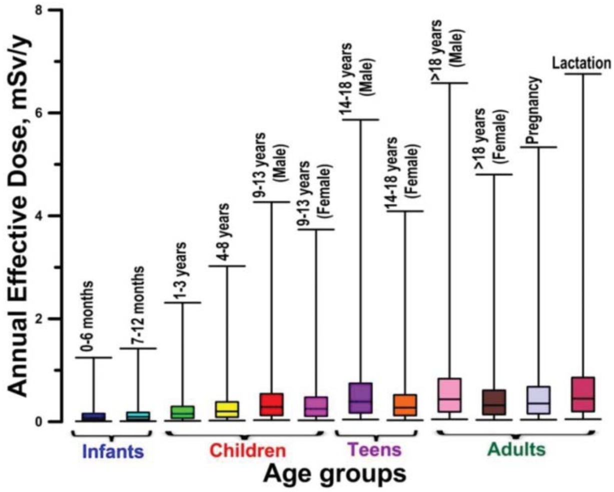

Figure 4. Comparison of the annually received effective dose in the different age groups.

liter ranged from 112.0 to 607.7 nSv/L (mean = 370.5 nSv/L) and was in the order: Lactating women>Adults males>Male teens>Pregnant Women>Adult females>Female teens>Male Children (9–13 years)>Female Children (9–13 years)>Children (4–8 years)>Children (1–3 years)>Infants (7–12 months)>Infants (0–6 months).

Estimation of annual effective dose

Comparative account on the annual effective dose received by different age groups/life stages are presented both numerically and schematically in Table 1 and Figure 4. The annual effective dose received by infants belonging to age groups of 0–6 months and 7–12 months, respectively, ranged from 0.003 to 0.622 mSv/y (mean: 0.082 mSv/y) and 0.003 to 0.711 mSv/y (mean: 0.093 mSv/y). Similarly, annual effective dose of 0.005–1.156 mSv/y (mean: 0.152 mSv/y) and 0.007–1.512 mSv/y (mean: 0.198 mSv/y) was received by the children in the age group of 1–3 and 4–8 years in contrast to the annual effective dose of 0.009–2.134 mSv/y (mean: 0.280 mSv/y) and 0.008–1.867 mSv/y (mean: 0.245 mSv/y), respectively, received by male and female children in the age group of 9–13 years. Likewise, male and female recipients categorized as teenagers (14–18 years age group) were found to receive an annual effective dose of 0.013–2.934 mSv/y (mean: 0.385 mSv/y) and 0.009–2.045 mSv/y (mean: 0.269 mSv/y), respectively. The proportion of the effective dose received by male and female adults (>18 years age groups) was in the range of 0.014–3.29 mSv/y (mean: 0.432 mSv/y) and 0.011–2.401 mSv/y (mean: 0.315 mSv/y), respectively. Further, effective dose to female recipients during pregnancy and lactation period was found to range from 0.012–2.667 mSv/y (mean: 0.350 mSv/y) and 0.015–3.379 mSv/y (mean: 0.444 mSv/y) respectively.

It is very clear from the results that annually received effective dose was higher for adult males and females during their lactation period over other age groups members (Figure 4) and was in the order: Lactating women>Adults males>Male teens>Pregnant women->Adult females>Female teens>Male Children>Female Children>Children (4–8 years)> children (1–3 years)>Infants (7–12 months)>Infants (0–6 months). It is also evident from the results that the effective dose in case of all age groups of males is higher compared to that for respective age groups of females under normal circumstances, probably due to their higher (on average) fat-free mass and energy expenditure besides higher water intake. Interestingly, intensified water consumption during pregnancy and lactation period in case of females has resulted in higher radiation dose in them (Duggal *et al.* 2016) and was in the order: Lactating women > Pregnant Women > Adult females. On the other end, in spite of having greater radio-sensitivity due to juvenile tissues, the portion of annual effective dose received by infants and children are on lower side as their quota of water consumption is very less compared to that of adults. The present findings were in agreement with the findings of Fakhri *et al.* (2016) in that annually received effective dose by male and female adults were higher than children and infants due to more water consumption. Moreover, significant transformations in the effective dose received by different age groups of infants, children, teens, adult men, and women can be attributed to variation in their amount of water consumption rate and utilization of same dose conversion coefficient for all age groups. Despite less per-capita drinking water consumption in infants, the study by Fakhri *et al.* (2016) reported higher effective dose for infants over children, probably due to usage of bigger conversion coefficient for infants over children and adults. Overall, it can be stated from the present study that amount of water consumption by lactating women and male adults over other age groups has resulted in higher annual effective dose in them compared to that for pregnant women, adult females, teenagers, children, and infants.

The mean annual effective dose ranges per person among four major age groups (*viz.*, infants, children, teens, and adults) caused by different water samples is also summarized in Figure 5. Among the four major age groups, the mean annual effective dose due to radon intake for majority of groundwater samples was below 0.5 mSv/y in 96.92%, 86.15%, 84.16%, and 84.16% of the samples, respectively. However, mean annual effective dose above 1 mSv/y was witnessed for people falling only under children, teens, and adults age groups, possibly due to higher water consumption over infants. Overall, the mean annual effective dose in 84.62% samples was less than 0.5 mSv/y irrespective of age groups. Of the remaining 15.38% samples, 7.69% each recorded mean annual effective dose between 0.5–1.0 and >1.0 mSv/y, respectively. The proportion of groundwater samples conceding an annual effective dose for different age groups higher than the recommended level of effective dose

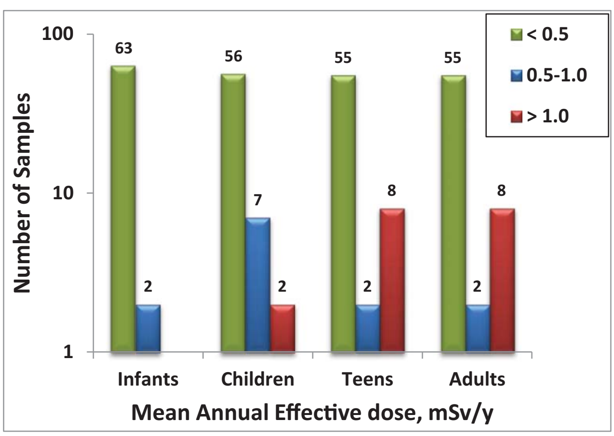

Figure 5. Histogram groups of mean annual effective dose.

to humans from water consumption of 100 μSv/y or 0.1 mSv/y (WHO 2004; EU 1998) is shown in Table 1. It was prominent that in majority of samples, the mean annual effective dose values received by all age groups were significantly lower than the UNSCEAR (2000) and WHO (1993) recommended limit of 1 mSv/y for public. These findings are in agreement with the findings of Ravikumar and Somashekar (2014) that the annual effective dose rate increases with increase in radon activity, age and annual water consumption rate. Overall, the annual effective doses were far below the maximum limit of 5 mSv/y set by the National Council on Radiation Protection and Measurements (NCRP 2004).

Conclusion

Radon concentrations have been determined for 65 drinking water samples collected from bore wells around Bangalore City. Elevated radon concentration recorded in 92.31% of the samples was above the United States environmental protection agency (USEPA) recommended guideline value of 300 pCi/L, corresponding to 11.1 Bq/L. The mean annual effective dose values received by all age groups were significantly lower than the UNSCEAR and WHO recommended limit of 1 mSv/y for public. Further, the effective dose was on the higher side in all the age groups of males compared with respective age groups of females under normal circumstances, probably due to higher (on average) fat-free mass and energy expenditure besides higher water intake rates. Interestingly, increased water consumption during pregnancy and lactation period in case of females has resulted in higher annual effective radiation dose. Overall, it can be concluded that radon in water is a big concern for public health in metropolitan cities like Bangalore, especially for consumers who directly use bore well water with very high radon concentration in household.

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